Moisture management of sportswear materials

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Materials used in the sportswear production should be able to maintain heat balance and have adequate moisture management to respond to intense sweating during sports activity. Previous studies have shown that a professional football player sweats 2193 +/- 365 ml during a game. The distribution and absorption of liquid on the textile surface depend on the intermolecular interactions. Since the next-to-skin materials used in sportswear are mainly knitted structures, the inter- and intra- yarn porosity plays a key role in moisture management. This paper focuses on the study of materials used for professional football sportswear from a moisture management perspective and discusses the influence of porosity.
Keywords: *moisture management, yarn, knitted fabric, materials, sportswear*

1. Introduction

Designing new textile products to improve human performance is an important area in the research and production of clothing such as protective and sportswear. In sportswear for active sports, performance is synonymous with comfort characteristics. For outdoor sportswear, the clothing should be able to protect the wearer from external elements such as wind, sun, rain and snow. At the same time, it should be capable of maintaining the heat balance between the excess heat produced by the wearer and the ability to dissipate body heat and perspiration [1].
The materials used in the manufacture of football apparel must have adequate moisture management to respond to the intense sweating that occurs during training and play. The intensity of sweating has been studied by a number of researchers. The study that focused on sweat loss in elite football players showed that the average sweat rate per hour was 1.39 l/h. Shirreffs *et al*. addressed the assessment of sweat rate in professional players during a training session that lasted 90 minutes [2]. The results showed a sweat loss rate of 2193 +/- 365 ml [3]. Both studies confirmed the intense sweat rate of football players, highlighting the importance of fabric structure design for optimal moisture management.

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Two processes responsible for liquid moisture transport are wetting and wicking. Wetting is a process at the interface when the air is replaced with a liquid, whilst the wicking is the process that starts when the liquid enters into the capillary formed between two fibres or yarns by the capillary forces [4, 5]. The spreading and absorption of the liquid over the textile surface depend on the intermolecular interactions, i.e. dipole-dipole interactions and London dispersion forces (commonly addressed as van der Waals forces), and hydrogen bonds. Additionally, textiles are heterogeneous and porous, characterized by dual-porosity, i.e. inter- and intra- yarn, so the porosity is crucial for moisture transport as well. Unlike the static methods of measuring these phenomena, the dynamic moisture transport in the fabric via liquid moisture management properties of textile fabrics can be measured using a moisture management tester (MMT) [5-9].

If the sweat and heat released from the body during exercise are not removed quickly enough, it can reduce the player's performance. Therefore, there is a need to study and quantify the parameters related to liquid moisture transport. In this paper, the parameters of liquid moisture transport are investigated in a set of knitted materials that differ in structure. The aim of the study is to describe the relationship between the structures of the materials made of polyester yarn to the liquid moisture management.

2. Experimental part

2.1. Materials

Within the experimental part, a set of designed knitted fabrics that are representative examples of materials used in the manufacture of football sportswear is investigated. The set consists of 5 knitted fabrics (hereafter referred to as F1-F5) made from polyester filament yarn of count 12 tex. The materials are knitted as structures with holes (specimens F1 and F3) and without holes (specimens F2, F4 and F5), the size of which varies, and is measured as described in the following section. The values of horizontal and vertical densities (Dh:Dv), representing the number of stitches in a length of 1 cm, are as follows: F1 - 16:18, F2 - 18:22, F3 - 11:14, F4 - 18:22, and F5 - 17:17.

2.2. Fabric measurements

The fabric mass per unit area is measured according to ISO 3801:1977, method 5. The specimen in size of 10 x 10 cm is cut and measured on an analytic scale produced by Kern, with an accuracy of +/- 0.001 g [10].

The fabric thickness is determined according to EN ISO 5084:1996 [11]. The thickness of the specimen is measured using the thickness meter DM 2000 - Wolf; Germany.

Dino-Lite Edge digital microscope is used to capture images of the studied fabrics. The images are further processed using Dino Capture 2.0 software to measure the surface of voids within the fabric stitches, i.e. intra-yarn porosity within the knitted structures. The measurements are taken at 10 places. The values of minimum and maximum area of intra-yarn pores are reported.

The evaluation and classification of liquid moisture management properties of selected knitted fabrics are determined using the M290 moisture management tester (MMT) [9] from SDL Atlas, which is shown in Figure 1. The measurement is performed according to AATCC TM 195-2021 [8]. Results are given as Wetting Time (WT) - the time period in which the top and bottom surfaces of the fabric just start to get wetted, Absorption Rate (AR) - the average speed of liquid moisture absorption for the top and bottom surfaces of the specimen during the initial change of water content during a test; Maximum Wetted Radius (MWR), Spreading Speed (SS) the accumulated rate of surface wetting from the centre of the specimen where the test solution is dropped to the maximum wetted radius, Accumulative One-way Transport Capability (OWTC) - the difference between the area of the liquid moisture content curves of the top and bottom surfaces of a specimen with respect to time, and Overall (liquid) Moisture Management Capability (OMMC) - an index of the overall capability of fabric to transport liquid moisture [5-9]. The grades are 1 Poor, 2 Fair, 3 Good, 4 Very Good, and 5 Excellent [9].

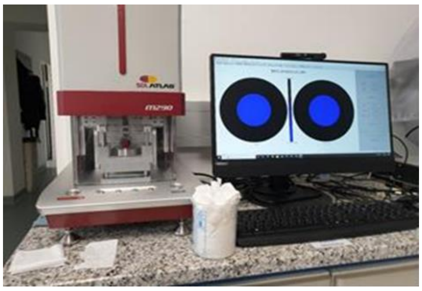

Fig.1 M290 moisture management tester (MMT) produced by SDL Atlas

3. Results and discussion

The ability to manage moisture is one of the most important properties that determine the comfort of sportswear fabrics. The results of the research, i.e., the measurements of fabric parameters and moisture management are presented and summarized in Figs. 2-10.

3.1. Fabric mass and thickness

The results of the mass per unit area measurement are shown in Fig. 2. In terms of mass per unit area, the values for specimens F1-F5 are within the range of 105 to 192 g/m².

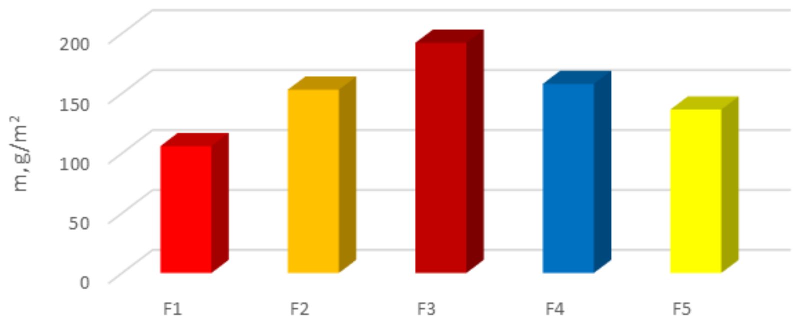

Fig.2 Fabric mass per unit area (m)

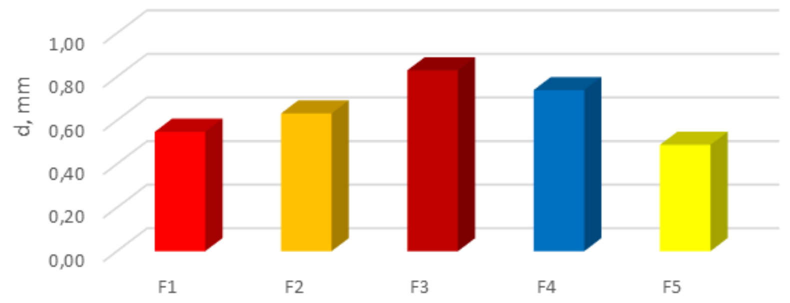

Fig.3 Fabric thickness (d)

The specimen assigned as F3 has the highest mass per unit area, while the specimen assigned as F1 has the lowest mass per unit area. When compared with the mass of specimen F3 the mass of specimen F1 is approximately 45% lower. The results of the knitted fabric thickness measurement are shown in Fig.3. As illustrated, the values are within the range of 0.488 to 0.830 mm. The specimen assigned as F3 has the highest thickness while the specimen assigned as F5 has the lowest. F3's thickness is approximately 41% greater than the one of F5.

Table 1 The minimum and maximum area of intra-yarn pores

Specimen	MIN, mm^2	MAX, mm^2
F1	0,133	0,665
F2	0,018	0,027
F3	0,016	1,752
F4	0,015	0,023
F5	0,020	0,041

Results in Fig.2 confirm that for observed specimens mass per unit area and thicknesses are corre-lated. As seen from the micro-scopic images of investigated fabrics, the specimens F1 and F3 are highly porous (the maximum size of pores is 0.665 and 1.752 mm^2, tab.1).

3.2. Moisture management

The obtained results for liquid moisture management properties, accor. to AATCC TM 195-2021, of specimens F1-F5 are summa-rized and shown in Fig.5-10. Wetting time (WT) for top and bottom surfaces, expressed in seconds (s) is the period in which either surface of the fabric became wet – that is, when the angle of total water content on either surface became greater than Tan (15°). The obtained results of WT are shown in Fig.5.
The values of the results of the first two specimens F1 and F2 are in the range of 10.06 to 12.67 s. The results for F1 and F2 have the highest values i.e. it takes the most time to get them wetted. The difference in values between WT top and bottom for both specimens is minimal. The values of the results for the other three specimens - F3, F4, and F5 - range from 3.8012 to 4.715 s, and there are also small differences between the results for top and bottom surfaces, suggesting that transport to the top surface is very rapid when the upper surface is wetted. The values for top and bottom surfaces of specimens F1 and F2 are greater, on average by 260% than specimens F3, F4, and F5. The reason for the slow wetting process of specimen F1 is in its pattern which has a certain amount of holes and the inter-yarn porosity is high. The liquid moisture gets accumulated in the pores, so the pore filling time is reflected at the height of the WT value. The absorption rate (AR) represents the average absorption of moisture by the top and bottom surfaces of a specimen during the wetting process. This is shown as the slope between the point at which the specimen becomes wet and the maximum point on the graph. The average AR is shown in percentage per second (%/s). The results for specimens F1- F5 are shown in Fig.6. Significantly, specimen F1 has the greatest difference between top and bottom values. The difference in values between the top and bottom surfaces for all other specimens, F2-F5, is, on average, 18%. In particular, specimen F1 showed the highest absorption rate on the bottom, as well as the fastest transfer from the top to the bottom surface, due to its high porosity.
The maximum wetted radius (MWR) is defined as the maxi-mum wetted ring at the top and bottom surfaces. The MWR is defined as a millimetre (mm). The obtained results of MWR for all five specimens are shown in Fig.7.

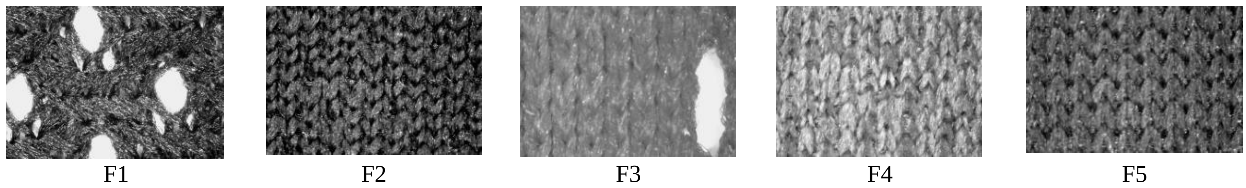

Fig.4 Microscopic images of investigated knitted fabrics

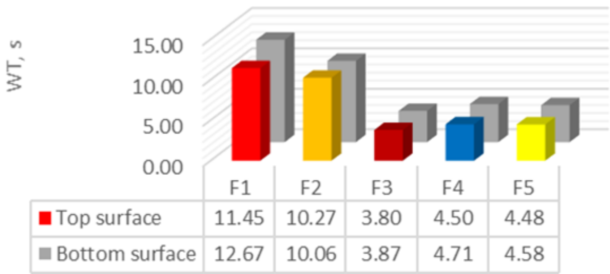

Fig.5 Wetting time (WT) of tested knitted fabrics

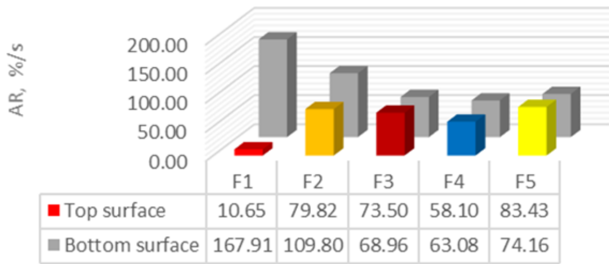

Fig.6 Absorption rate (AR) of tested knitted fabrics

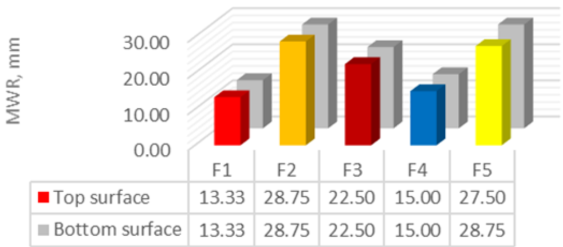

Fig.7 Wetted radius (MWR) of tested knitted fabrics

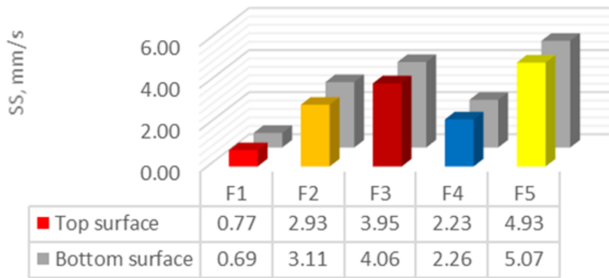

Fig.8 Spreading speed (SS) on tested knitted fabrics

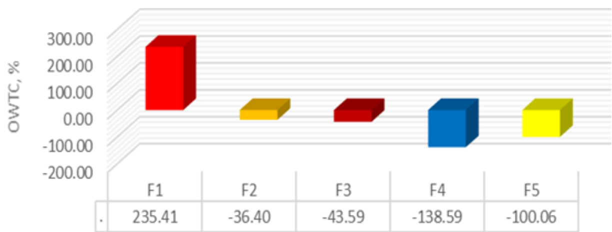

Fig.9 Accumulative one-way transport index (OWTC) of tested knitted fabrics

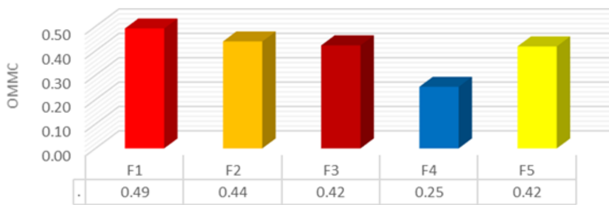

Fig.10 Overall moisture management capability (OMMC) of tested knitted fabrics

Spreading speed (SS) is defined in millimetre per second (mm/s) as the cumulative spreading speed from a specimen's centre to its maximum wetted radius in (mm/s) on both top and bottom surfaces. The results for knitted fabrics F1-F5 are shown in Fig.8.

The wetted radius of specimens F2 and F5, with an average value of 28 mm, is the highest among investigated specimens (Fig.7). This correlates with its spreading speed shown in Fig.8. The values for specimens F1, F3, and F4 are in the range of 13 to 22 mm. There is no observed difference between top and bottom values for all specimens except F5, whose difference is negligible – less than 5%. Specimen F1 has the lowest spreading speed, with a value of 0.6894 mm/s for its bottom surface. The obtained values for all the other specimens (i.e. the specimens F2- F5) are four to seven times higher in the range of 3 to 5 mm. As seen from the graphical presentation, specimen F5 has the greatest value. There is no significant difference between the top and bottom values for any of the specimens. Comparing the results with the horizontal and vertical densities of investigated fabrics, it can be concluded that densities do not significantly affect the observed property.

Accumulative one-way transport capability (OWTC) represents the difference in the accumulative moisture content between two surfaces of a specimen concerning time. The indexes of OWTC, for specimens F1-F5, are presented in Fig.9. Among specimens, only specimen F1 has a positive value. A positive value indicates that the water content on the top surface is higher than the water content on the bottom. The results, therefore, suggest that the fabric F1 has high absorbency.

Overall, (liquid) moisture management capability (OMMC) represents a fabric's capacity to transfer liquid moisture [6]. The obtained results of OMMC for knitted fabrics F1-F5 are shown in Fig.10.

OMMC combines three measure-able aspects: the liquid moisture absorption rate of the fabric's bottom side, the one-way liquid transfer capability, and the maxi-mum liquid moisture spreading speed on a fabric's bottom surface. Based on the results, the MMT can identify 7 types of fabrics: waterproof fabric, water repellent fabric, slowly absorbing and slow drying fabric, fast-absorbing and slow drying fabric, fast-absorbing and quick-drying fabric, water penetration fabric, and moisture management fabric [9]. The results for specimens F1, F2, F3, and F5 have similar ratings, they are in the range of 0.42 to 0.49. The specimen assigned as F4 has the lowest value of 0.25. This is also a specimen with higher values of horizontal and vertical density.

The Grading Summary Table is presented in tab.2. The table includes fabric types according to their performance [8,9]. As can be seen from the data given, the OMMC for the specimens F1, F2, F3, and F5 is defined as "good", while the rate for specimen F4 is defined as "fair".

Table 2: Grading Summary Table for knitted fabrics F1-F5 according to AATCC TM 195-2021

Measured property	**Fabric**				
	F1	**F2**	**F3**	**F4**	**F5**
Top wetting time, s	3	3	4	4	4
Top absorption rate, %/s	2	4	4	4	4
Top wetted radius, mm	3	5	4,5	3	5
Top spreading speed, mm/s	1	3,5	4	3	5
Bottom wetting time, s	3	3	4	4	4
Bottom absorption rate, %/s	5	5	4	4	4
Bottom wetted radius, mm	3	5	4,5	3	5
Bottom spreading speed, mm/s	1	3,5	5	3	5
Accumulative one-way transport index, %	3	2	1,5	1	1
Overall moisture management capability	3	3	3	2	3

The results characterized the knitted fabrics F2, F3, and F5 as fast-absorbing and quick-drying fabrics. That means their wetting time is in value from medium to fast as well as their absorption rate. The property of this fabric is fast spreading, and a large spreading area, but poor one-way moisture transport capability. This type of fabric is very useful for sportswear to respond to intensive sweating during training and matches. The fabric assigned as F4 is characterized as a fast-absor-bing and slow-drying fabric. It differs from fast-absorbing and quick-drying fabrics, with the property of a slow and small spreading area of moisture. The results of knitted fabric F1 have characterized this specimen as moisture management fabric with the greatest one-way transport i.e. fabric that ensures body dryness. All investigated knitted fabrics in this research with their fast absorption moisture capability can transfer sweat and heat, realized from the body during sports activities, enough quickly to en-hance the comfort of sportswear.

4. Conclusion

As outlined in the introduction, the materials used in the manufacture of football apparel must have adequate moisture management to respond adequately during periods of intense sweating. In this paper, the parameters of liquid moisture transport are studied in a series of knitted materials used in the manufacture of sportswear, which differ in structure.

The analysis of the obtained results showed that a high inter-yarn porosity affected highest absorption rate on the bottom, as well as the fastest transfer from the top to the bottom surface. All the knitted fabrics studied have fast absorption moisture capability and can effectively transfer sweat from the body of an athlete to the environment. Still, there are diffe-rences between the fabrics based on their structures. According to the results, three of the five tested fabrics are defined as fast absor-bing and quick-drying, one as fast-absorbing and slow drying and one as a moisture management fabric. The moisture management fabric has the greatest one-way transport i.e. this fabric is expected to assure optimal body dryness.

Further scientific efforts should focus on the study of different influencing parameters on moisture management and the use of different methods to describe this property.

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